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The study of soil phosphorous status and availability in soils of Urmia Plain, Iran

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Abstract

Soil nutrients mapping and monitoring are of great importance to reach the goals of sustainable agriculture. In developing countries, neglecting soil test results in unbalanced fertilization of soils. The aim of this research was to investigate soil phosphorous (P) availability and mapping in soils of Urmia Plain, northwest Iran. 277 soil samples from an area of 900 km^2 of agricultural lands were taken. Soil samples were gathered from the depth 0-30 cm on a grid of 0.7-1 km. Samples were sieved and analyzed for macro and micro nutrients, organic carbon, calcium carbonate equivalent and clay. In order to map the soil P_{av}, logarithmic transferred values were used to develop variogram. Then spatial prediction of soil salinity was done on a grid of 500 m using ordinary kriging. Results showed that soil samples commonly had P deficiency based on Olsen critical level of 15 ppm. However, small area at the center of the study area had high values of P_{av}. Correlation analysis revealed that there were significant correlations (1% probability level) between P_{av} with organic matter, potassium and copper. The application of the organic fertilizers from sewage slug sources could result in local increase of soil P up to 100 mg/kg or more, while in other parts of the area soil available P is normally below 30 mg/kg. According to the findings of this research, neither organic fertilizers nor chemical fertilizers are not being used based on soil test which can be a problem for both sustainable production and environmental health.

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Introduction

Urmia Plain is located at the west of Urmia Lake, northwest Iran. It is one of the biggest Plains in Iran and is an important agricultural productions region in the area. During past decades, many of the rain fed agricultural lands in this area have changed to irrigated ones. The expansion of irrigated agriculture along with traditional irrigation systems have resulted in unsustainable use of water resources. This has turned out to be one of the major reasons of Urmia Lake dry up. The crisis of Urmia Lake dry up which has led to huge saline barren lands near agricultural farms has raised concerns about water usage in agricultural sector in one hand and the possibility of secondary salinization of agricultural lands in the other hand (Hamzehpour *et al.*, 2013).

Recently, a lot of pressure has been put on farmers (whose lives depend on agriculture) to reduce water usage. From now on, keeping agricultural productions yield at their optimum level along with the least water usage at each square meter of a land with the minimum damage to the environment is becoming an important issue. To do so, it is very important to keep soils at their best condition, which means least but best use of fertilizers. This is not possible unless soil test and nutrient condition in soils be taken seriously as it is in developed countries. Therefore soil nutrients mapping and monitoring are of great importance in order to reach the goals of sustainable agriculture (Goetz and Keusch, 2005).

Phosphorous (P) is one of the essential elements for plants optimum growth. It is necessary for photosynthesis, cell division, and energy transfer. It is needed in relatively large amounts in plants and its deficiency constantly affects plants functions and growth (Mengel *et al.*, 2001). P is being adsorbed largely in the form of $H_2PO_4^-$ by plants' roots. By increasing the soil pH, HPO_4^- becomes the common form of available P (P_{av}) in soils. In calcareous soils of arid and semi-arid regions of the world like Urmia Plain, soil phosphorous becomes unavailable due to the formation of the non-soluble compounds (Halajnia *et al.*, 2007). In these areas yearly thousands of tons of P fertilizers are being added to the soils in order to compensate plant's needs (Chen *et al.*, 2012; Shi *et al.,* 2015). However, huge amounts of these fertilizers precipitate as insoluble compounds resulting in deficiencies of P_{av} (Sympson *et al*, 2015). Therefore in calcareous soils usually over use of chemical P fertilizers not only don't solve the problem, but also raises another problem which is microelements deficiencies as they also can bond with phosphate ions and precipitate from soil solution to solid phase (Shaepley *et al.*, 1989). For above reasons, besides adding chemical fertilizers, farmers also add organic materials such as sewage slug to their soils. These substances contain considerable amounts of phosphorus (Herzel *et al.*, 2016) and also can bond with heavy metals which sometimes results in addition of toxic amounts of heavy metals and phosphorus to the soil (Livens, 1991; Ferreiro-Dominguez *et al.*, 2016**).**

There have been several studies on soil P availability in calcareous soils and the role of organic fertilizers in this regard (Halajnia *et al.*, 2007; Yazdanpanah *et al.*, 2013; Ferreiro-Dominguez *et al.*, 2016**).** However, attempts to map and monitor spatial variations of soil P haven't been much (Page *et al.*, 2005; Roger *et al.*, 2014; Piotrowaska-Dlugosz *et al.*, 2016). Therefore the aim of this research was to investigate P and some other nutrients availability and soil P mapping in soils of Urmia Plain, northwest Iran in order to practically open a window to the status of the soils regarding the sustainability of agricultural activity and productions in the region.

Material and methods

Study area

The study area includes 900 km² of lands in the western part of Urmia Lake, north-west of Iran (Fig. 1). It is located between 45° 13" to 45° 55" E and 37° 20" to 37° 53" N. The mean annual precipitation is 367 mm. The mean annual temperature for the coldest month is -5.2°c and for the warmest one is 32°c. Potential evaporation in the area is between 900-1170 mm. In terms of geology, the study area is composed of two different deposits: saline playa deposits and young alluvial terraces and alluvial fans with very low salinity.

Soil sampling and analysis

Soil samples were taken from agricultural lands on a grid of 0.7-1 km. 277 samples were gathered from depth 0-30 cm (Fig.1).

Fig. 1. Study area and sampling locations in West Azarbaijan, northwest Iran.

In each sampling point, in order to get a homogeneous soil sample, 10 separate soil samples were taken within 1m radius and then samples were mixed. In each mixed sample, available Phosphorous (P_{av}) (Olsen and Sommers, 1982); exchangeable Potassium (K) (Knudsen *et al*, 1982); available Iron (Fe), Zinc (Zn), Manganese (Mn), Copper (Cu) (Lindsay and Norvell, 1978), soil texture with hydrometer method (Bouyoucos, 1962), organic matter (OM) with acid digestion method (Page and Miller, 1982) were measured.

Spatial perdition of soil phosphorous

Ordinary kriging (OK) method was used to spatial prediction of soil P. the details of developing spatial variogram and OK method are discussed in detail (Li and Heap, 2008). Mean error (ME), mean square error (MSE) and correlation coefficient (r) were chosen to compare the results. All of the analyses were done in BMElib toolbox (Christakos *et al*., 2002) written for Matlab (MathWorks, 2010).

Results and discussion

Statistical analysis

Statistical analysis of soil samples are presented in Table 1. According to Table 1, nutrients avaiability varied largely among soil samples, from very low to high values. Soil P had large variations from 1.9 to 346 $mg.kg^{-1}$ in the area (Table 1). Mean value of 21.7 $mg.kg^{-1}$ and S.D of 33.64 for soil P showed that generally soil samples had low values rather than high ones. Considering the critical level of 15 ppm in calcareous soils (Olsen and Sommers, 1982), sampling points with values lower than 15 ppm were marked and presented (Fig. 2a). According to Fig. 2a, large numbers of soil samples gathered from all over the study area, represented P deficiency. However, soil samples from relatively middle of the study area (Fig. 2 b), contained high values of avaiable P.

Table 1. Summary statistics of essential elements and some other soil properties.

	N	Mean	S.D	Min	Max	Skewness
P (mg.kg^{-1})	277	21.7	33.64	1.9	346	5.60
K (mg.kg^{-1})	277	454.30	190.54	38.8	1200.67	0.47
Fe (mg.kg^{-1})	277	3.83	4.74	0.14	50.94	5.80
Zn (mg.kg^{-1})	277	0.76	0.75	0.04	5.32	3.15
Mn (mg.kg^{-1})	277	4.35	3.75	0.3	21.88	1.45
Cu (mg.kg^{-1})	277	1.65	0.92	0.26	5.92	0.78
O.M (%)	277	21.79	0.83	0	3.9	1.45
TNV (%)	277	13.50	6.25	0.25	34	0.60
Clay (%)	123	33.95	12.76	4	66	0.11

Table 2. Correlation among soil available phosphorous and other essential nutrients (mg/kg), O.C (%), TNV (%).

	Phosphor	Potassium	Iron	Zinc	Manganese	Copper	O.C	TNV
Phosphor	1	0.121**	-0.021	0.031	0.033	0.079**	0.120**	0.025
NO. samples	276	276	276	276	276	276	276	276

Spatial prediction of available P

According to Table 1, P dataset included a wide range of Values with S.D of 33.64 and Skewness of 5.6, therefore logarithmic transferred of P data was used in order to detect any spatial dependency among dataset. Results showed that using logarithmic transferred data led to the S.D of 0.95 and skewness of 0.67. Therefore P dataset could be assumed to have normal distribution and kriging estimator could be used as prediction method. Later, to check the spatial correlation of the P dataset, variogram model was fitted on the 2/3 of dataset (remaining kept for the validation of the predictions). Results showed that there was a spatial relation among dataset.

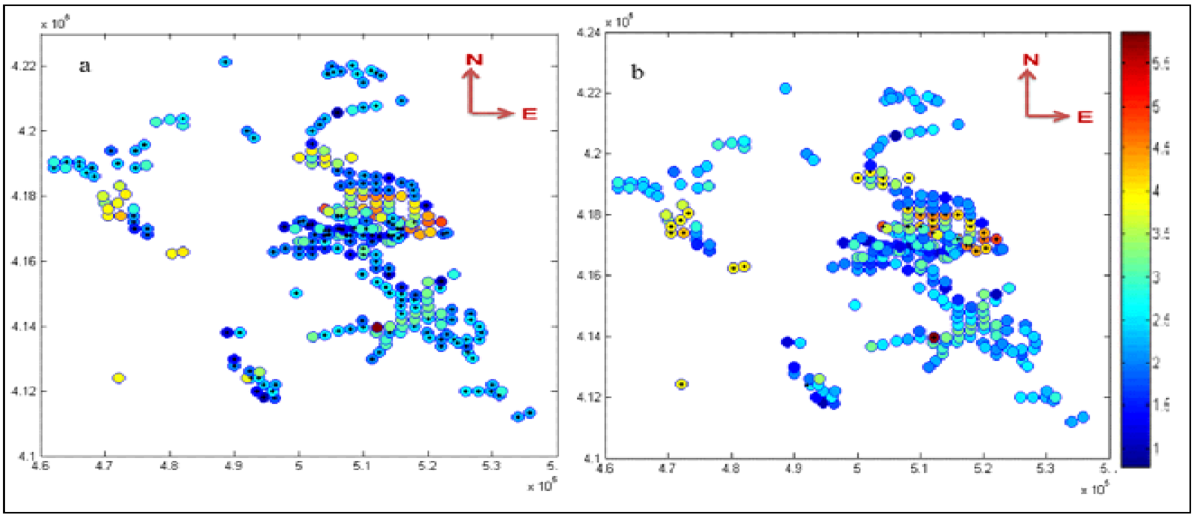

Fig. 2. Sampling locations for Soil P$_{av}$. Colours reflect soil P values on a log scale. dots corresponds to locations with high or low values of soil P. a: sampling locations with P deficiencies (lower than 15 ppm); b: sampling locations with high P values (above 40 ppm).

The best varigram model fitted on the dataset was a spherical model with a nugget effect equal to 0.4, sill of 0.95 and rage of 4.5 km (Fig. 3a). Then spatial prediction of soil P was done on a grid of 500 m (Fig. 3b). Validating the predicted map with 1/3 of the dataset showed that ordinary kriging had successfully predicted the soil P with r, ME and MSE equal to 0.85, -0.18 and 0.33 respectively. Cheng *et al* (2016) also successfully used classical kriging in spatial prediction of soil total P in a small watershed of Dan River in China.

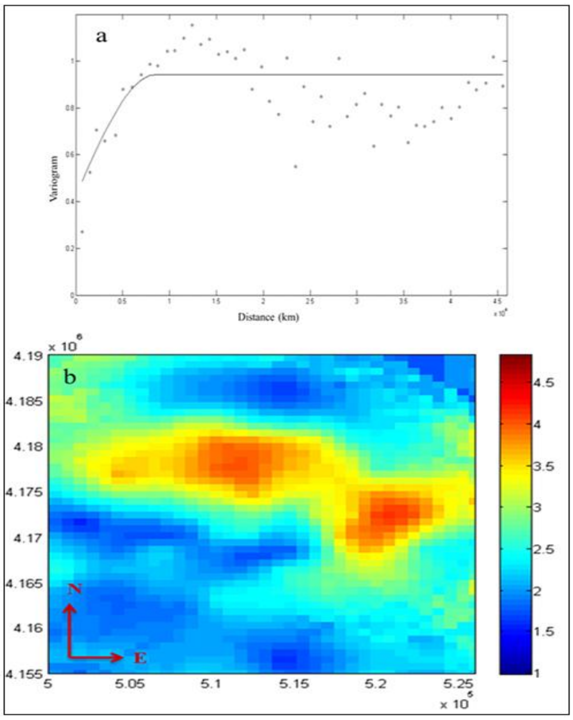

Fig. 3. a: Spatial variogram for soil P prediction. b: Soil P prediction map using ordinary kriging.

To investigate the reasons for the large variations of soil P in the study area, where agricultural activities are the most common land use, soil P was correlated to other macro and microelements.

Soil TNV and O.C were also taken in to account (Table 2). According to Table 2, soil P_{av} significantly correlated to soil available K, O.C and Cu in 1% probability level.

Colorplot of soil K distribution and areas with available K lower than 300 $mg.kg^{-1}$ (Fig. 4b) showed that although K deficiency was not as common as it was for P_{av} (Fig. 4a), but any sampling location with P_{av} deficiency, also represented K deficiency. This is because when farmers use fertilizers, they usually add P-K fertilizers at the same time and when they don't, they use neigher of them.

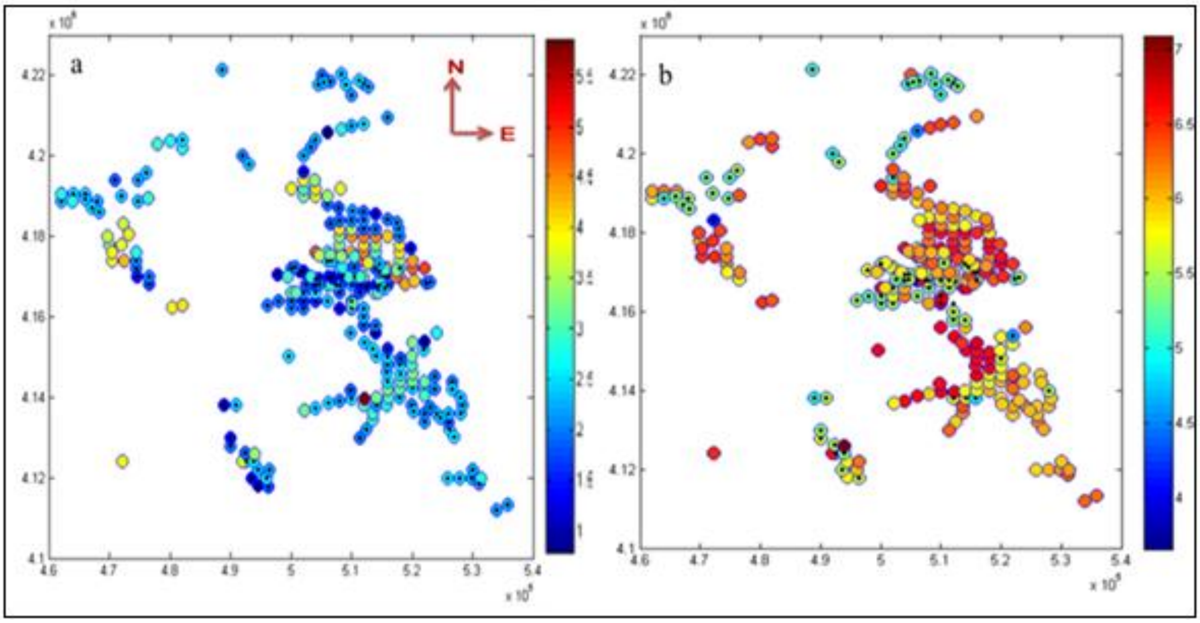

Fig. 4. Soil sampling locations and values of P_{av} and K. low values of Soil P_{av} (in log scale) and K are presented with dots. Colours reflect variation in values. a: soil P_{av}; b: soil K.

Therefore, usually P-K nutrients' deficiencies or their high dosages appear at similar locations. The good corelation between soil P_{av} and K proves the above statement (Table 2).

However, In several researches P contamination in soils is also reported (Leopold *et al*., 2006; Pease *et al*., 2010; Chen *et al*., 2012). This could be due to local overuse of chemical P-fertilizers (Marquez-Molina *et al*., 2014). Xi *et al*. (2016) found that the threshold range of soil Olsen-P is from 12.5 to 30.6 $mg.kg^{-1}$ to optimize crop yields and to maintain relatively low risk of P leaching. According to Table 2, available P showed significant correlation with soil O.M. especially in P values above 40 **mg.kg⁻¹** and O.M above 2% (Fig. 5). As this has happened in limited number of sampling locations (Fig. 3b, areas presented in warm colors), it seems that application of organic fertilizers like sewage slug could result in local increase of soil P_{av} even up to 100 mg/kg or more (Ferreiro-Dominguez *et al.*, 2016), while in other parts of the area soil P_{av} is normally below 30 mg.kg⁻¹**.** Lin *et al.* (2016) found that soil O.M and nitrogen influence dissolved P loads.

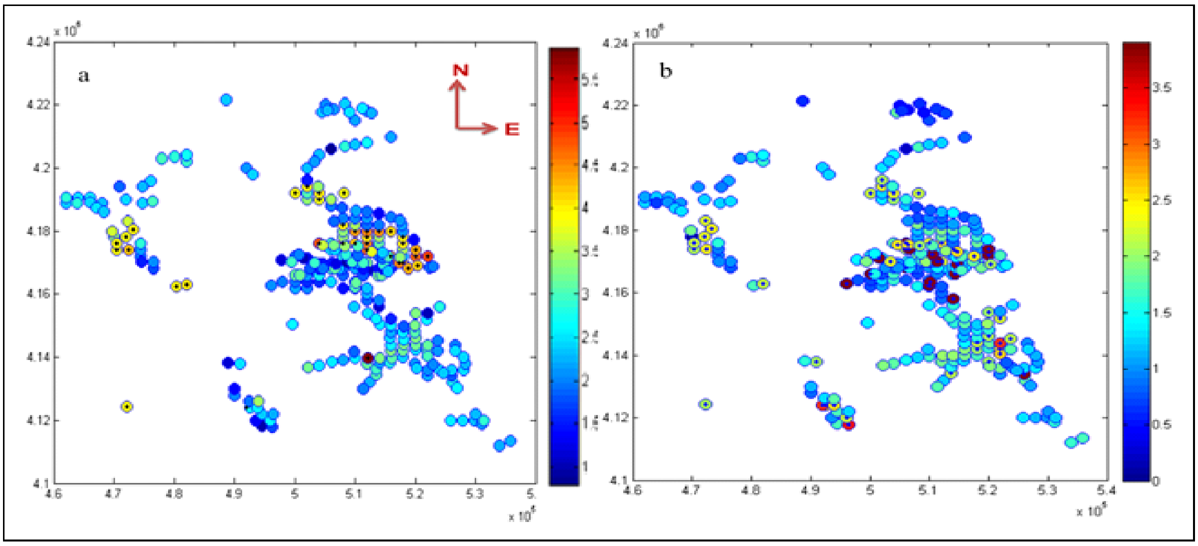

Fig. 5. Soil sampling locations and values of P_{av} and O.M. High values of Soil P_{av} (in log scale) and O.M are presented with dots. Colours reflect variation in values. a: soil P_{av}; b: soil O.C.

Yazdanpanah *et al.* (2013) also found that P availability increased due to the application of organic amendments. It has been said that replacement of adsorbed P ions by humate ions results in increased amounts of available P in soil. Studies have shown that addition of low molecular weight organic substances to the soil increases the activity of Al-P and Fe-P bonds in low and neutral pH conditions and Ca-P in higher pH values. This can lead to the increase of available P level in soil solution and as of its consequence, more P will be available for plants' roots (Zhuo *et al.*, 2009; Zhang *et al.*, 2009).

Conclusion

Among studied soil samples, soil available P (P_{av}) indicated large variations, however, P_{av} deficiency was widespread in all over the study area. Logarithmic transformed values of P_{av} showed relatively normal distribution and lead to the successful spatial prediction of soil P_{av} using ordinary kriging with r, ME and MSE equal to 0.85, -0.18 and 0.33 respectively. Predicted map revealed that a small area at the centre of the study area had high values of the P_{av}. Correlation studies between P_{av} and other soil nutrients and properties showed a significant correlation between P_{av} and soil organic matter (O.M), potassium (k) and copper (Cu) in 1% probability level.

Due to the low availability of P in calcareous soils of the Urmia Plain, farmers sometimes use organic substances like sewage slug in the study area which can be the reason for locally increase of P_{av}. According to the findings of this research, neither organic fertilizers nor chemical fertilizers are not being used based on soil test which could be a problem for both sustainable production and environmental health.

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